The National Park Service

YELLOWSTONE NATIONAL PARK

MONITORING AND RESEARCH ON BISON AND BRUCELLOSIS

Prepared by:
P. J. White, Chief, Wildlife and Aquatic Resources
Rick Wallen, Bison Ecology and Management Program
John Treanor, Yellowstone Wildlife Health Program

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PURPOSE AND RATIONALE FOR MONITORING

The successful conservation of plains bison (*Bison bison*) in and near Yellowstone National Park from about two dozen animals in 1901 to about 4,700 animals in 2013 has led to an enduring series of disagreements among various management agencies and stakeholder groups regarding bison abundance and distribution, and the potential transmission of the disease brucellosis (which causes abortions) from bison to domestic cattle (Plumb et al. 2009). Also, since the State of Montana and the National Park Service (NPS) agreed in 2000 to the court-mediated Interagency Bison Management Plan (IBMP; U.S. Department of the Interior [USDI] and U.S. Department of Agriculture [USDA] 2000a, b), progress has been slow at completing the plan’s successive management steps. Thus, the U.S. Government Accountability Office (2008) recommended that the agencies responsible for implementing the IBMP develop specific management objectives, conduct monitoring to evaluate the effects and effectiveness of management actions, and develop methods for adjusting the IBMP based on these assessments. These recommendations were implemented through an adaptive management plan developed in 2008 (USDI et al. 2008), and as a result, there is an ongoing need to estimate key parameters of bison and brucellosis dynamics, and evaluate the likely effects and effectiveness of a variety of management activities. This report provides findings on a suite of long-term monitoring and research activities that are intended to inform adaptive management and related decision making.

MONITORING ACTIVITIES

The various types of actions in the IBMP to conserve Yellowstone bison while lessening the risk of brucellosis transmission to cattle in Montana can be grouped into three general categories: 1) conserving a viable population of wild bison and the ecological processes that sustain them; 2) managing brucellosis transmission risk from bison to cattle; and 3) reducing the prevalence and transmission of brucellosis in bison (Figure 1). Thus, we developed management and research objectives for these desired conditions that are multidimensional and involve trade-offs, whereby improving an outcome associated with one objective affects outcomes associated with other objectives (Williams et al. 2007). We also developed one or more sampling objectives for each monitoring activity (White et al. 2008).

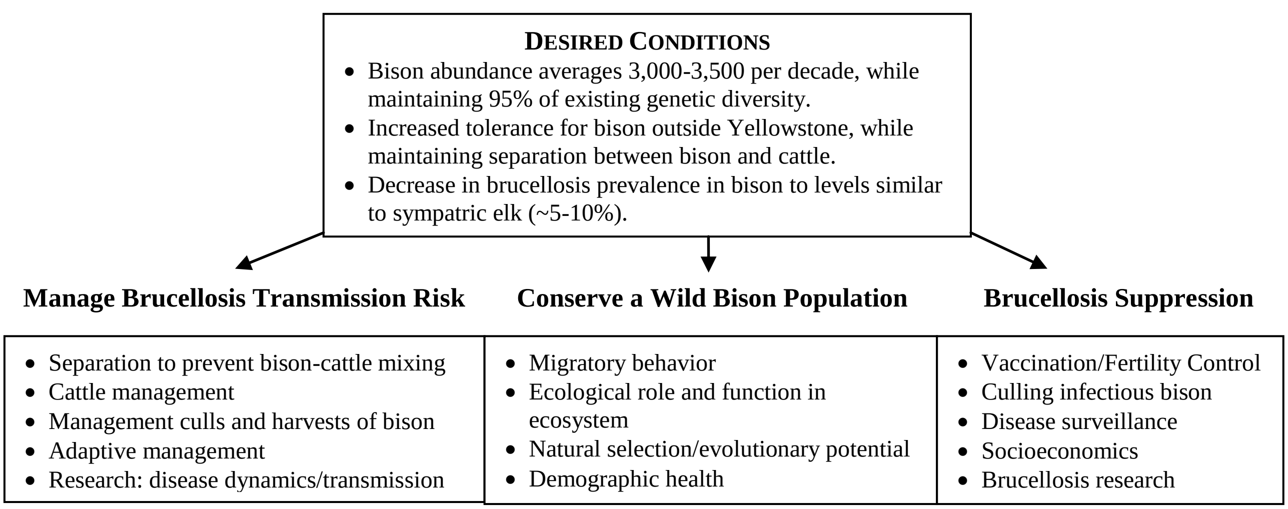

Figure 1. Conceptual model of conservation and brucellosis management for Yellowstone bison.

The following monitoring activities were then developed to provide timely and useful information to help develop adaptive management adjustments.

Conservation (Preserve a Functional, Wild Bison Population)

1. Estimate the abundance, demography, and limiting factors for the overall bison population and two primary subpopulations (i.e., central and northern breeding herds).
2. Describe migratory and dispersal movements by bison at a variety of temporal and spatial scales in and outside the park.
3. Estimate the existing heterozygosity, allelic diversity, and long-term probabilities of genetic conservation for the overall bison population and identified subpopulations.
4. Promote cooperative conservation in bison management by partnering with states, American Indian tribes, and others interested in bison health and recovery.

Risk Management (Lessen Brucellosis Transmission from Bison to Livestock)

5. Estimate the probabilities (i.e., risks) of brucellosis transmission among bison, cattle, and elk, and between the elk feed grounds in Wyoming and northern Yellowstone.
6. Estimate age-specific rates of bison testing seropositive and seronegative for brucellosis that are also culture positive, and the portion of seropositive bison that react positively on serologic tests due to exposure to cross-reactive agents other than *Brucella abortus* (e.g., *Yersinia*).
7. Estimate the timing and portion of removals from the central and northern herds each winter, including the portion of removals from each age and sex class and calf-mother pairs.
8. Document bison use of risk management zones outside the northern and western boundaries of Yellowstone and commingling with livestock during the likely brucellosis-induced abortion period for bison each spring.
9. Estimate the effects of hazing or temporarily holding bison in capture pens at the boundary of Yellowstone (for spring release back into the park) on subsequent bison movements or possible habituation to feeding.

Brucellosis Suppression (Reduce Brucellosis Prevalence)

10. Determine the strength and duration of the protective immune responses in bison following vaccination for brucellosis via a hand-held syringe.
11. Determine the strength and duration of protective immune responses in bison following vaccination for brucellosis via remote delivery (i.e., without capture; e.g. bio-bullet).
12. Document long-term trends in the prevalence of brucellosis in bison, and the underpinning effects of remote and/or syringe vaccination, other risk management actions (e.g., harvest, culling), and prevailing ecological conditions (e.g. winter-kill, predation) on these trends.

IMPLEMENTATION AND EXPECTED OUTCOMES

To accomplish this suite of monitoring activities, NPS staff work with the other IBMP members (Animal and Plant Health Inspection Service, Confederated Salish and Kootenai Tribes of the Flathead Nation, InterTribal Buffalo Council, Montana Department of Livestock, Montana Fish, Wildlife & Parks, Nez Perce Tribe, U.S. Forest Service), and other scientists and stakeholders to implement field, controlled, and laboratory studies to collect empirical data for evaluating progress. The data are used to develop and inform models that serve as analytical tools for evaluating how bison and brucellosis may respond to management actions given existing uncertainties about, and annual variations in, the system. The IBMP members produce an annual report that describes monitoring activities, the status of Yellowstone bison, and relevant brucellosis management issues. The Wildlife Biologist leading the Bison Ecology and Management Program at Yellowstone is responsible for producing the NPS portion of the annual IBMP report, which is disseminated at <http://ibmp.info/>. In addition, the Wildlife Biologist (Bison) is responsible for managing the monitoring system described herein and posting pertinent reports and articles at <http://www.nps.gov/yell/naturescience/bisonrefs.htm>. Articles resulting from monitoring will be subject to peer review by other scientists from the NPS, agency partners, and/or anonymous reviewers selected by editors of scientific journals. Pursuant to Bulletin M-05-03 issued by the Office of Management and Budget on December 16, 2004, the intensity of peer review will be commensurate with the significance of the information being disseminated.

Success in adaptive management ultimately depends on effectively linking monitoring and assessment to objective-driven decision making (Williams et al. 2007). Though different philosophies exist regarding how adaptive management should be implemented, certain concepts are pervasive, including: 1) linking key steps such as identifying objectives, implementing monitoring, and adjusting management actions based on what is learned; 2) collaborating with agency partners; and 3) communicating with and engaging key stakeholders (U.S. Government Accountability Office 2008). This monitoring program will provide timely and useful information to help develop adaptive management adjustments needed to conserve Yellowstone bison, reduce the risk of brucellosis transmission from bison to cattle, and reduce the prevalence of brucellosis in the bison population. It will also allow IBMP managers to track system responses to these management actions through continuation of monitoring. Examples of actions by the NPS that monitoring may trigger based on the information collected include:

- Deciding whether or not to implement remote vaccination based on vaccine efficacy (i.e., stimulation of cellular immunity) and the development of adequate delivery options to obtain the desired reductions in seroprevalence and infection;
- Discontinuing vaccination in its implemented form if there is no indication of progress over a reasonable period;
- Implementing conservation measures to decrease mortality and increase the growth rate of the population if bison abundance decreases towards 2,500;
- Altering culling or harvest strategies if significant and biologically important effects to age, genetics, herd, and/or sex structure are detected;
- Recommending actions to substantially increase harvests and culls if bison abundance exceeds 4,500;
- Discontinuing brucellosis containment or suppression actions if bison abundance decreases below 2,500 and agency partners do not strictly implement conservation measures to abate further reductions in abundance.

MONITORING SYSTEM EVALUATION

The monitoring program will be considered successful if it provides data to: 1) evaluate progress towards achieving objectives; 2) identify appropriate management actions and adjust management decisions; 3) reduce uncertainty by comparing predictions against survey data; and

4) develop and enhance models of the system as needed and appropriate (Williams et al. 2007). Each year through regularly scheduled IBMP meetings, completion of the annual IBMP report, and update of this monitoring plan, we solicit review, comment, and discussion by our agency partners and key stakeholders in the refinement of objectives, design of monitoring, and assessment to provide a foundation for learning-based resource management. Public information personnel share the results of monitoring activities with stakeholders through timely press releases and web-mails, and reports and articles are made available on-line at websites for the IBMP (http://ibmp.info/) and bison (http://www.nps.gov/yell/naturescience/bisonrefs.htm).

MONITORING FINDINGS

The following paragraphs summarize findings of monitoring and research since the adaptive management plan for the IBMP was initiated in 2008. These findings were reported at IBMP meetings and considered by the IBMP members in developing annual reports and recommendations for adaptive management adjustments (White et al. 2009, Zaluski et al. 2010, Canfield et al. 2011, Jones et al. 2012, Clarke et al. 2013).

Conservation (Preserve a Functional, Wild Bison Population)

1. Estimate the abundance, demography, and limiting factors for the overall bison population and two primary subpopulations (i.e., central and northern breeding herds).

    - Bison abundance, age and sex structure, and recruitment are estimated each summer for the central and northern breeding herds. Results are documented in an annual count report that is posted on the website for the IBMP (http://ibmp.info/). A sample of 30 to 60 radio-collared bison is maintained annually to estimate condition, distribution, group sizes, habitat use, movements, pregnancy, and survival. These findings are released periodically in published articles (see below).

    - NPS staff collaborated with colleagues at Montana State University to estimate demographic rates from 80 adult female bison in the central herd during 1995-2006 (Geremia et al. 2009).
        - Animals testing positive for exposure to brucellosis had significantly lower pregnancy rates across all age classes compared to seronegative bison.
        - Birth rates were high and consistent for seronegative animals, but lower for younger, seropositive bison. Seronegative bison that converted to seropositive while pregnant were likely to abort their 1st and 2nd pregnancies.
        - There was a pronounced decrease in survival for animals >12 years old. Also, brucellosis exposure indirectly lowered bison survival because more bison were culled over concerns about transmission to cattle when bison attempted to move to lower-elevation areas outside the park.
        - There was a significant decrease in adult female survival when the number of bison in the central herd exceeded 2,000-2,500 animals, which was exacerbated during winters with severe snow pack because more bison moved outside the park. Except during 1996-1997, the vast majority of radio-marked bison culled at the north and west boundaries during 1995-2006 likely came from the central herd.

    - The effects of brucellosis on survival and birth rates lowered the growth rate in the central herd. Population growth rates would likely increase by more than 15% if substantial brucellosis suppression was successful.

- NPS staff collaborated with colleagues at Colorado State University to synthesize available information and interpreted results from a spatially explicit model (Coughenour 2005) of the Yellowstone system (Plumb et al. 2009).
    - Bison abundance has not exceeded the theoretical food-limited carrying capacity of about 6,200 in Yellowstone.
    - More bison migrate earlier to lower-elevation winter ranges as numbers increase and climatic factors interact with density to limit nutritional intake and foraging efficiency.
    - A gradual expansion of the winter range as bison numbers increased enabled relatively constant population growth and increased food-limited carrying capacity.
    - Current management actions should attempt to preserve bison migration to essential winter range areas within and adjacent to the park, while actively preventing dispersal and range expansion to outlying areas via hazing, translocations, and culls.
    - A population of 2,500-4,500 bison should satisfy collective interests concerning the park's forage base, bison movement ecology, retention of genetic diversity, brucellosis risk management, and prevailing social conditions.

- NPS staff contributed to a chapter on conservation guidelines for population, genetic, and disease management of American bison for the International Union for Conservation of Nature (Gates et al. 2010).
    - Overarching principles for conserving bison were to (1) maximize the number of bison in a population (i.e., 'maximum sustainable' rather than a 'minimum viable' population size) to better retain natural variation and provide more resiliency to 'surprises' or catastrophic events, (2) support and promote 'wild' conditions and behaviors in an environment where bison are integral to community and ecosystem processes, exposed to natural selection, and active management interventions are minimized, (3) preserve genetic integrity and health by maintaining bison lineages and carefully evaluating all movements of bison between populations, and (4) conducting routine monitoring and evaluation of demographic processes, herd composition, habitat, and associated ecological processes that are central to evaluating herd health and management efficacy.

- NPS staff developed a population model using data collected from Yellowstone bison during 1970-2012 and estimated the abundance, composition, and trends of each breeding herd to evaluate the relative impacts of harvests and other types of management removals (Geremia et al. 2011a, 2012, 2013).
    - Demographic estimates were integrated with a model of bison migration (Geremia et al. (2011b) to predict the numbers of bison moving to the park boundary each winter. These tools combined long-term monitoring data with information gained from radio-collared bison to draw conclusions about future conditions of Yellowstone bison.
    - A decision-making process was developed to advise the management of population abundance and trans-boundary movements of bison. During June and early July, NPS

staff conducted population counts and age and gender classifications of each breeding herd. They then used long-term weather forecasts and the models described above to predict herd abundances and compositions at the end of the upcoming winter, and the magnitude of numbers of bison migrating to park boundaries.
    - NPS staff established annual removal objectives for bison based on abundance, disease, distribution, and demographic (age, herd, sex) goals to reduce bison numbers towards an end-of-winter guideline of 3,000, while maintaining more than 1,000 bison in the central and northern breeding herds, similar proportions of males to females (range = 40-60%), and an age structure of about 70% adults and 30% juveniles (range = 22-33% juveniles).
    - A variety of management tools were considered for reducing bison numbers including (1) public and treaty harvests in Montana, (2) culling (shipment to slaughter facilities or terminal pastures) at boundary capture facilities, (3) selective culling (shooting, shipment to slaughter) in Montana to prevent brucellosis transmission to nearby livestock or due to human safety or property damage concerns, (4) transfer of bison to American Indian tribes or other organizations for quarantine and eventual release, and (5) transfer bison to research facilities.

- Scientists from the U.S. Geological Survey, Northern Rocky Mountain Science Center, investigated the pregnancy rates of central Yellowstone bison based on necropsies of animals that were culled at the western boundary during 1997 to 2003 (Gogan et al. 2013).
    - Pregnancy rates increased with body weight and age, which are highly correlated indicators of body condition (fat, protein) that strongly influence the probability of pregnancy in many ungulates.
    - There was some evidence that a high portion of bison did not breed successfully in sequential years, with most pregnancies occurring in bison at least 3 years old that were not lactating.
    - During some years, lactating bison may not be able to achieve a critical body fat to support pregnancy by autumn if weather conditions (e.g., drought) or high herbivore densities (i.e., competition) contribute to marginal summer nutrition.
    - Pregnancy rates of females appeared unaffected by brucellosis exposure.

- NPS collaborated with Syracuse University (Dr. Douglas Frank) during 2011-2013 to quantify forage production and consumption at six study sites across the northern grasslands in Yellowstone National Park. Five or six grazing exclosures were deployed at each site. Production and percent consumption estimates were made monthly from May to September. During the 1980s and 1990s, migratory ungulates on the northern grassland of Yellowstone had tight biogeochemical linkages with plants and soil microbes that doubled the rate of net nitrogen mineralization, stimulated aboveground production by as much as 43%, and stimulated belowground productivity by 35% (Frank and McNaughton 1993). These biogeochemical linkages were largely driven by high densities of elk that deposited large quantities of nitrogen, phosphorus, and other nutrients via dung and urine. However, rates of ungulate grazing intensity and grassland nitrogen mineralization were reduced by 25-53% by 1999-2001, partially as a result of 60% fewer elk (Frank 2008). Since 2002, bison numbers in northern Yellowstone have almost quadrupled from 813 to 3,200. Larger groups of grazing bison could potentially have quite different effects than elk on nutrient redistribution and cycling on northern Yellowstone grasslands (Frank et al. 2013). This project should help elucidate the influence of recent changes in elk and bison numbers and distributions on ecosystem processes such as the spatial pattern and intensity of ungulate grazing and grassland energy and nutrient dynamics.

- NPS biologists and their colleagues published a book entitled *Yellowstone's Wildlife in Transition* (White et al. 2013a) that contains many chapters with information about the status and ecology of bison, as well as their management history and current challenges. Chapters with information pertinent to bison include:
    - Understanding the past: The history of wildlife and resource management in the greater Yellowstone area (Olliff et al. 2013);
    - Scale and perception in resource management: Integrating scientific knowledge (Becker et al. 2013);
    - Population dynamics: Influence of resources and other factors on animal density (White and Gunther 2013);
    - Predation: Wolf restoration and the transition of Yellowstone elk (White and Garrott 2013);
    - Competition and symbiosis: The indirect effects of predation (Garrott et al. 2013);
    - Climate and vegetation phenology: Predicting the effects of warming temperatures (Wilmers et al. 2013);
    - Migration and dispersal: Key processes for conserving national parks (White et al. 2013c);
    - Assessing the effects of climate change and wolf restoration on grassland processes (Frank et al. 2013);
    - Balancing bison conservation and risk management of the non-native disease brucellosis (Treanor et al. 2013); and
    - The future of ecological process management (White et al. 2013b).

2. Describe migratory and dispersal movements by bison at a variety of temporal and spatial scales in and outside the park.

- NPS staff collaborated with colleagues at Montana State University to quantify annual variations in the magnitude and timing of migration by central herd bison during 1971-2006 and identify potential factors driving this variation (Bruggeman et al. 2009c).
    - Bison from the central herd were partially migratory, with a portion of the animals migrating to the lower-elevation Madison headwaters area during winter while some remained year-round in or near the Hayden and Pelican valleys.
    - There was significant bison migration to the Madison headwaters area before the Hayden and Pelican valleys were fully occupied and abundance approached the food-limiting carrying capacity of these valleys.
    - After the central herd exceeded 2,350 animals, however, the number of bison wintering in the Hayden and Pelican valleys appeared to stabilize, while bison continued to migrate to the Madison headwaters area. Also, more bison migrated earlier as density increased.

    - Some bison migrated outside the west-central portion of the park between the summer and winter counts each year when the central herd exceeded 2,350 bison, perhaps relocating to northern range.
    - The timing and magnitude of bison migration were accentuated during years of severe snow pack that limited access to food.

- NPS staff collaborated with colleagues at Montana State University to quantify how snow, topography, habitat attributes, and roads influenced the travel patterns and non-traveling activities of 30 radio-marked, adult, female bison from the central herd during three winters (Bruggeman et al. 2009a, b).
    - Bison were less likely to use a point on the landscape for traveling or feeding as snow pack increased. However, bison used local areas with deeper snow as the overall snow pack increased on the landscape.
    - Distance to stream was the most influential habitat covariate, with the spatial travel network of bison being largely defined by streams connecting foraging areas. Distances to foraging areas and streams also significantly influenced non-traveling activities, being negatively correlated with the odds of bison foraging or resting.
    - Topography significantly affected bison travel patterns, with the probability of travel being higher in areas of variable topography that constrained movements (e.g., canyons). Distance to road had a significant, negative effect on bison travel, but was nine times less influential compared to the impact of streams.
    - Road grooming has a minimal influence on bison travel and habitat use given the importance of natural dynamic and static landscape characteristics such as snow pack, topography, and habitat attributes on bison choice of travel routes and habitat use for foraging and resting.

- NPS staff collaborated with staff from Colorado State University to analyze the relationships between bison population size, winter severity, and the number of bison removed near the boundary of Yellowstone during 1990-2010 (Geremia et al. 2011b).
    - Migration differed at the scale of breeding herds (central, northern), but a single unifying exponential model was useful for predicting migrations by both herds.
    - Migration beyond the northern park boundary was affected by herd size, accumulated snow water equivalent, and aboveground dry biomass. Migration beyond the western park boundary was less influenced by these predictors, and model predictions since 2006 suggest additional drivers (e.g., learning) of migration were not in the model.
    - Simulations of migrations over the next decade suggest that a strategy of sliding tolerance where more bison are allowed beyond park boundaries during severe climate conditions may be the only means of avoiding episodic, large-scale reductions to the Yellowstone bison population in the foreseeable future.

3. Estimate the existing heterozygosity, allelic diversity, and long-term probabilities of genetic conservation for the overall bison population and identified subpopulations.

    - NPS staff collaborated with colleagues at the University of Montana to test the hypothesis that bison from the central and northern breeding herds would be genetically differentiated based on mitochondrial and microsatellite DNA from fecal samples.

  - Based on mitochondrial DNA analyses, there was significant genetic differentiation between bison sampled from the northern and central breeding herds, likely due to strong female fidelity to breeding areas (Gardipee 2007).

- NPS staff provided information to the Department of Interior for review by scientists from government agencies and non-governmental organizations with professional population geneticists and the development of guidance for the genetic management of federal bison populations (Dratch and Gogan 2010).
  - Parks and refuges that currently have bison populations, with the exception of Yellowstone National Park, do not have enough land to support a population of more than 1,000 bison (i.e., minimum target to preserve genetic variation over centuries).
  - Yellowstone bison have relatively high allelic richness and heterozygosity compared to other populations managed by the Department of Interior.
  - Yellowstone bison are the only population with no molecular evidence (i.e., microsatellite markers) or suggestion (i.e., SNPs) of potential cattle ancestry (i.e., introgression of cattle genes). Thus, this population constitutes a genetic resource that must be protected from inadvertent introgression.
  - The Yellowstone and Wind Cave bison populations are genetically unique and the lineages are not represented elsewhere within populations managed by the Department of Interior. Thus, high priority should be given to replicating these significant lineages via satellite herd establishment (Halbert and Derr 2008).

- The NPS reviewed a study by Pringle (2011) that concluded that some Yellowstone bison have deleterious genetic mutations, and as a result, “are predicted significantly impaired in aerobic capacity, disrupting highly evolved cold tolerance, winter feeding behaviors, escape from predators and competition for breeding."
  - Bison with haplotype 6 in their mitochondrial genome carry a double mutation that affects two genes: Cytochrome b and ATP6. These bison are primarily found in the central breeding herd based on recent genetic sampling. This inherited mutation could affect their production of energy (i.e., ATP produced by mitochondrial oxidative phosphorylation). Bison with haplotype 8 in their mitochondrial genome do not carry the double mutation and are primarily found in the northern breeding herd.
  - Even if the genetic sequences and analyses reported by Pringle (2011) are correct, genetic mutation does not automatically equal genetic disease. There are multiple compensating mechanisms in biological systems that combine to overcome theoretical metabolic deficiencies.
  - Also, there is direct evidence that even if Yellowstone bison have some sort of genetic deficiency, it has not been manifested through any biologically significant effect on their ability to survive. Estimated annual survival rates and birth rates for adult female bison were quite high during 1995-2013; especially given the severe, prolonged, high-elevation winter conditions and predator-rich environment in and near Yellowstone National Park.
  - The NPS is conducting research with Dr. Jim Derr at Texas A&M University to follow-up on Dr. Pringle's work and recommendations.

- NPS staff collaborated with colleagues at the University of Montana and to conduct a mathematical modeling assessment that provided predictive estimates of the probability of preserving 90 and 95% of the current level of genetic diversity values (both heterozygosity and allele diversity) in Yellowstone bison (Pérez-Figueroa et al. 2012).
  - Findings suggested that variation in male reproductive success had the strongest influence on the loss of genetic variation, while the number of alleles per locus also had a strong influence on the loss of allelic diversity.
  - Fluctuations in population size did not substantially increase the loss of genetic variation when there were more than 3,000 bison in the population. Conservation of 95% of the current level of allelic diversity was likely during the first 100 years under most scenarios considered in the model, including moderate-to-high variations in male reproductive success, population sizes greater than 2,000 bison, and approximately five alleles per locus, regardless of whether culling strategies resulted in high or low fluctuations in abundance.
  - However, a stable population abundance of about 2,000 bison was not likely to maintain 95% of initial allele diversity over 200 years, even with only moderate variation in male reproductive success. Rather, maintenance of 95% of allelic diversity is likely to be achieved with a fluctuating population size that increases to greater than 3,500 bison and averages around 3,000 bison.

- NPS staff collaborated with colleagues at University of Montana to conduct DNA extractions with fecal samples collected from Yellowstone bison in the northern and central breeding herds during 2006 and 2008.
  - Mitochondrial DNA analyses revealed two haplotypes, with higher frequency of haplotype 8 in the northern breeding herd, and significant genetic differentiation among northern and central herds ($F_{ST} = 0.40$[1]).
  - Microsatellite analyses revealed allele frequencies with low levels of subdivision between the central and northern breeding herds ($F_{ST} = 0.02$ in 2006 and 0.01 in 2008).
  - These results suggest the population has two genetically distinguishable breeding groups with strong female philopatry and male-mediated gene flow.
  - Radio-marked adult females provided evidence of female fidelity, but emigration between breeding groups was substantial during 2007-2012.
  - Staff recommended long-term monitoring of microsatellite allele and mitochondrial haplotype frequencies to track genetic diversity and population substructure. They expect F_{ST} values to fluctuate as the population responds to bison density in the two breeding herds, management actions (e.g., culling), and natural selection.

- In a study partially funded and supported by the NPS, Halbert et al. (2012) investigated the potential for limited gene flow across the Yellowstone bison population using blood and hair samples primarily collected from bison at the northern and western boundaries of the park during the winter migration period, well after the breeding season.
  - Two genetically distinct and clearly defined subpopulations were identified based on both genotypic diversity and allelic distributions. Genetic cluster assignments were

[1] F_{ST} is the portion of total genetic variance contained in a subpopulation compared to the total genetic variance. Values can range from 0 to 1 and high F_{ST} implies considerable differentiation among subpopulations.

highly correlated with sampling locations for a subgroup of live capture individuals. Furthermore, a comparison of the cluster assignments to the two principle winter cull sites revealed critical differences in migration patterns across years.
    - The two Yellowstone subpopulations displayed levels of differentiation that are only slightly less than that between populations which have been geographically and reproductively isolated for over 40 years.
    - The authors suggested that the continued practice of culling bison without regard to possible subpopulation structure has the potentially negative long-term consequences of reducing genetic diversity and permanently changing the genetic constitution within subpopulations and across the Yellowstone population.

- NPS staff (White and Wallen 2012) disputed some of the assumptions and inferences made by Halbert et al. (2012) and suggested that human manipulation had created and maintained much of the observed population subdivision and genetic differentiation.
    - Extensive monitoring of the movements and productivity of radio-collared bison since 2005, when the population reached an abundance of approximately 5,000 bison, suggests that emigration and gene flow is now much higher than suggested by Halbert et al. (2012). Allowing the bison to migrate and disperse between breeding herds would be in the best interest of the bison population for the long term.
    - The NPS will continue to allow ecological processes such as natural selection, migration, and dispersal to prevail and influence how population and genetic substructure is maintained in the future rather than actively managing to perpetuate an artificially created substructure. The existing population and genetic substructure may be sustained over time through natural selection or it may not.

- Scientists at Colorado State University investigated genetic natural resistance to brucellosis in Yellowstone bison by attempting to identify resistant and susceptible genotypes using the prion protein gene (PRNP; Herman 2013).
    - Analyses failed to support the hypothesis that the prion protein gene can be used as a screening tool for brucellosis susceptible genotypes in bison. This finding contrasts with that of Seabury et al. (2005) who reported a significant association between the prion protein gene and bison testing positive for *Brucella* exposure.
    - Management of brucellosis based on genetic screening would require further studies of the bison genome that would include representative samples from both breeding herds and with equally distributed sex and brucellosis serology ratios.
    - An evaluation of 42 microsatellite loci indicated Yellowstone bison retain high genetic diversity and that a high percentage of adult animals contribute offspring.
    - There was no evidence of cattle DNA introgression.

4. Promote cooperative conservation in bison management by partnering with states, American Indian tribes, and others interested in bison health and recovery.

- During 2005 through 2008, 214 Yellowstone bison calves that tested negative for brucellosis exposure were transferred from the NPS to the Animal and Plant Health Inspection Service and Montana Fish, Wildlife & Parks. These bison were moved to a research quarantine facility north of Yellowstone National Park to evaluate if they would remain free of brucellosis through at least their first pregnancy and calving.

  - The quarantine feasibility study (2005 through 2010) was successful and the surviving original bison and their offspring are considered brucellosis-free by the State of Montana and the Animal and Plant Health Inspection Service (Montana Fish, Wildlife & Parks 2010, 2011).
  - The State of Montana completed environmental compliance to relocate 87 of these bison to the Green Ranch owned by Turner Enterprises Inc. in February 2010 and the remaining 61 bison to the Fort Peck Indian Reservation in March 2012. Pursuant to memoranda of understanding, these bison are undergoing five additional years of assurance testing to increase public and scientific confidence that the bison are truly brucellosis-free.
  - In December 2013, there were about 250 Yellowstone bison at the Green Ranch, including the surviving original bison and their offspring. All of these bison remain the property of the State of Montana until February 2015, at which time Turner Enterprises Inc. will return to Montana Fish, Wildlife & Parks all the surviving original bison from the quarantine feasibility study and 25% of their offspring. At that time, Turner Enterprises Inc. will gain ownership of the remaining offspring.
  - In August 2013, the Fort Peck Assiniboine and Sioux Tribes transferred 34 Yellowstone bison to the Fort Belknap Reservation. As a result, 38 Yellowstone bison remained at the Fort Peck Indian Reservation in December 2013. Per agreement, up to 25% of the progeny of these bison will be made available to the State of Montana.

- In September 2012, the Superintendent of Yellowstone National Park signed an agreement with the InterTribal Buffalo Council for occasionally transferring some Yellowstone bison to them for transport to slaughter and subsequent distribution of bison meat and other parts to American Indian tribes. A similar agreement was signed with the Confederated Salish and Kootenai Tribes in February 2013.

- In September 2012, the NPS reinitiated consultation with the U.S. Fish & Wildlife Service under Section 7(a)(2) of the Endangered Species Act and its implementing regulations (50 CFR Part 402.16) regarding the hazing of Yellowstone bison and its potential effects on threatened grizzly bears, as well as new information on decreases in key grizzly bear foods. The NPS prepared a biological evaluation that provided updated information, an evaluation of potential effects, and descriptions of mitigation actions that should minimize potential adverse effects. NPS staff concluded that bison hazing operations may affect, but are not likely to adversely affect, listed grizzly bears. The Fish & Wildlife Service concurred with this conclusion in December 2012.

- During October 2012, staff at Yellowstone National Park consulted with members of American Indian tribes associated with Yellowstone National Park during two conference phone calls regarding the management of Yellowstone bison and possible transfers of bison to the tribes.

- Staff at Yellowstone National Park worked with the federal, state, and tribal agencies involved with the management of Yellowstone bison to develop a protocol in November 2012 that describes the requirements, roles, and responsibilities that would apply when live Yellowstone bison are transferred from the NPS to American Indian tribes or other recipients to be transported to slaughter facilities, terminal pastures, or quarantine facilities.

- In November 2012, staff at Yellowstone National Park developed a proposal for the Director of the NPS to consider establishing an operational quarantine facility that can eventually hold up to 1,000 bison and transferring approximately 250 Yellowstone bison testing negative for brucellosis exposure to the facility for several years. Bison that successfully complete the quarantine requirements would be considered brucellosis-free and could be used for conservation and/or to support the culture and nutrition of American Indian tribes.

- NPS staff evaluated historical records to determine whether any evidence exists to support the contention that Native Americans hunted or were permitted to hunt in Yellowstone National Park during the twentieth century. Also, staff researched the history and chronology of bison, elk, and bear meat from Yellowstone National Park being distributed to various American Indian tribes after the animals were shot inside park boundaries by the NPS (Whittlesey 2013).
  - A search of park collections by archivists, curators, and historians did not find any evidence of Native Americans ever being given permission to legally hunt within Yellowstone National Park during the twentieth century, or evidence of any policies generated by the NPS related to such activities.
  - However, NPS staff did find substantial information about the distribution of bison and elk meat to various American Indian tribes after animals were shot inside the park by NPS personnel during the ungulate reduction program from 1932 to 1967. In some cases, Native Americans were allowed to do the butchering of the carcasses in Yellowstone National Park and these activities may have led to misperceptions about Native Americans hunting bison and elk inside the park.
  - Alternatively, it is possible that some informal agreement or arrangement to allow Native Americans to hunt in the park existed with some Tribe(s) or tribal members, but evidence of such permission or practice can no longer be located.

<u>Risk Management (Lessen Brucellosis Transmission from Bison to Livestock)</u>

5. Estimate the probabilities (i.e., risks) of brucellosis transmission among bison, cattle, and elk, and the elk feed grounds in Wyoming and northern Yellowstone.

   - NPS staff collaborated with colleagues at the Agricultural Research Service and University of Montana to genotype 10 variable number of tandem repeat DNA loci in 58 *Brucella abortus* isolates from bison, elk, and cattle and test which wildlife species was the likely origin of recent outbreaks of brucellosis in cattle in the greater Yellowstone area (Beja-Pereira et al. 2009).

    - Findings suggested that isolates from cattle and elk were nearly identical, but highly divergent from bison isolates. Thus, elk, not bison, were the reservoir species of origin for these cattle infections.

- NPS staff collaborated with colleagues at the U.S. Geological Survey and other agencies and universities to assess several plausible hypotheses for observed increases in the seroprevalence of brucellosis in several free-ranging elk populations of Wyoming (Cross et al. 2010).
    - Free-ranging elk appear to be a maintenance host for *Brucella abortus* in some areas.
    - Brucellosis seroprevalence in free-ranging elk increased from 0-7% in 1991-1992 to 8-20% in 2006-2007 in four herd units not associated with feed grounds.
    - These seroprevalence levels, which are comparable to units where elk are aggregated on feed grounds, are unlikely to be sustained by dispersal of elk from feeding areas with high seroprevalence or an older age structure.
    - The rate of seroprevalence increase was related to the population size and density of each herd unit. Enhanced elk-to-elk transmission in free-ranging populations may be occurring due to larger winter elk aggregations.
    - Elk populations inside and outside of the greater Yellowstone area that traditionally did not maintain brucellosis may now be at-risk due to recent population increases. In particular, some neighboring populations of Montana elk were 5-9 times larger in 2007 than in the 1970s, with some aggregations comparable to the Wyoming feed ground populations.

- The NPS reviewed and provided comments on a draft of the Kilpatrick et al. (2009) article that used a model to integrate epidemiological and ecological data to quantify and assess the spatiotemporal relative risk of transmission of *Brucella* from bison to cattle outside Yellowstone National Park under different scenarios.
    - The risk of transmission of brucellosis from bison to cattle is likely to be a relatively rare event, even under a ‘no plan’ (no management of bison) strategy.
    - The risk of transmission of brucellosis from bison to cattle will increase with increasing bison numbers and severe snow fall or thawing and freezing events.
    - As the area bison occupy outside Yellowstone in the winter is enlarged and overlaps cattle grazing locations, the risk of transmission will increase. Thus, adaptive management measures to minimize risk of transmission will be most effective.
    - Risk of transmission could be effectively managed with lower costs, but land use issues and the larger question of bison population management and movement outside the park might hinder the prospect of solutions that will please all stakeholders.

- NPS staff estimated the timing and location of parturition events that may have shed tissues infected by *Brucella abortus* during April to mid-June, 2004-2007 (Jones et al. 2010).
    - Observed abortions occurred from January through May 19, while peak calving (80% of births) occurred from April 25 to May 26, and calving was finished by June 5.
    - Observed parturition events occurred in Yellowstone National Park and on the Horse Butte peninsula in Montana, where cattle were not present at any time of the year.

- Allowing bison to occupy public lands outside the park where cattle are never present (e.g. Horse Butte peninsula) until most bison calving is completed (late May or early June) is not expected to significantly increase the risk of brucellosis transmission from bison to cattle because: 1) bison parturition is essentially completed weeks before cattle occupy nearby ranges; 2) female bison consume many birthing tissues; 3) ultraviolet light and heat degrade *Brucella abortus* on tissues, vegetation, and soil; 4) scavengers remove fetuses and remaining birth tissues; and 5) management maintains separation between bison and cattle on nearby ranges.
- Allowing bison to occupy public lands outside the park through their calving season will help conserve bison migratory behavior and reduce stress on pregnant females and their newborn calves. The risk of brucellosis transmission to cattle can still be minimized though effective management of bison distribution.

- NPS staff collaborated with colleagues at Montana State University to analyze conditions facilitating contact between bison and elk on a shared winter range in the Madison headwaters area of Yellowstone during 1991 through 2006 (Proffitt et al. 2010).
  - Spatial overlap between bison and elk increased through winter as snow pack increased and peaked when late-term abortion events and parturition occurred for bison. Wolves contributed to immediate, short-term responses by elk that increased spatial overlap with bison, but longer-term responses to wolves resulted in elk distributions that reduced spatial overlap with bison.
  - Despite this relatively high risk of transmission, levels of elk exposure to *Brucella abortus* (2-4%) were similar to those in free-ranging elk populations that do not commingle with bison (1-3%), suggesting that *Brucella abortus* transmission from bison-to-elk under natural conditions is rare.
  - Management of brucellosis in elk populations could focus on reducing elk-to-elk transmission risk and, to the extent feasible, curtailing practices that increase elk density and group sizes during the potential abortion period.

- NPS staff collaborated with colleagues at Colorado State University to develop Bayesian models to estimate rates of incidence and routes of transmission of *Brucella abortus* bacteria among Yellowstone bison during 1995-2010 and assessed the reproductive costs (C. Geremia, National Park Service, unpublished data).
  - The median probabilities of horizontal (from unrelated bison) and vertical (from mother) exposure to calves were 0.10 (95% credible interval = 0.03-0.22) and 0.10 (0.00-0.28), respectively; though the distribution for vertical transmission was skewed left with most of the probability closer to zero.
  - Probabilities that adult bison were exposed to brucellosis since the preceding parturition season varied from 0.03-0.37 and snow pack severity exacerbated incidence.
  - There was a measureable probability (0.01-0.12) of bison recrudescing from a latent to an infectious state.
  - There was a reproductive cost of diminished birth rates following brucellosis infection, with only 59% of seropositive and recently seroconverting females with calves compared to 79% of seronegative females with calves.

    - These results suggest brucellosis is maintained through mixed transmission modes and the duration of infection may extend beyond the acute phase.

  - NPS and Animal Plant and Health Inspection Service staff and the State Veterinarian of Montana collaborated with colleagues at the University of California-Davis on a spatially-explicit assessment of brucellosis transmission risk among bison, elk, and cattle in the northern portion of the greater Yellowstone area (Schumaker et al. 2010).
    - Population size and winter severity were major determinants influencing bison movements to lower elevation winter grazing areas that overlapped with private ranches and federally-regulated cattle grazing allotments. Increasing population size resulted in higher bison densities and increased bacterial shedding.
    - Median total risk to cattle from elk and bison was 3.6 cattle-exposure event-days (95% probability interval = 0.1-36.6). The estimated percentage of cattle exposure risk from Yellowstone bison was small (0.0-0.3% of total risk) compared with elk (99.7-100% of total risk).
    - Natural bison migration patterns and boundary management operations were important for minimizing brucellosis exposure risk to cattle from bison, which supports continued boundary management operations for separation between bison and cattle.
    - Transmission risks to elk from elk in other populations or from bison were small. Minimal opportunity exists for *Brucella abortus* transmission from bison to elk under current natural conditions in the northern greater Yellowstone area.
    - Management alternatives that reduce brucellosis prevalence in bison are unlikely to substantially reduce transmission risk from elk to cattle. Strategies that decrease elk densities, group sizes, and elk-to-elk transmission could reduce the overall risk to cattle grazing in the northern portion of the greater Yellowstone area.
    - Efforts should be taken to reduce the mingling of cattle and elk, especially during the late gestation period for elk, when spontaneous abortions pose a risk for interspecies disease transmission.
    - Bison vaccination did not meaningfully reduce *Brucella abortus* transmission risk to cattle. Effective risk reduction strategies included delaying the turn-on dates of cattle grazing allotments, reducing brucellosis prevalence in elk, reducing the number of cattle at-risk, and preventing the mingling of elk and cattle.

- Staff from the Montana Department of Fish, Wildlife & Parks estimated the persistence of bacteria on fetal tissue, soil, and vegetation, and scavenging on infectious materials from birth and abortion sites near the northern and western boundaries of Yellowstone National Park during 2001-2003 (Aune et al. 2012).
    - *Brucella* bacteria can persist on fetal tissues and soil or vegetation for 21-81 days depending on month, temperature, and exposure to sunlight. Bacteria purposely applied to fetal tissues persisted longer in February than May and did not survive on tissues beyond June 10 regardless of when they were set out.
    - *Brucella abortus* field strain persisted up to 43 days on soil and vegetation at naturally contaminated bison birth or abortion sites.
    - Fetuses were scavenged by a variety of birds and mammals in areas near Yellowstone National Park and more rapidly inside than outside the park boundary.

    - Models derived from the data indicated a 0.05% chance of bacterial survival beyond 26 days (95% Credible Interval of 18-30 days) for a contamination event in May.

- The University of Montana and collaborators (including the NPS) examined transmission of *Brucella abortus* between bison, elk, and cattle using nine variable-number tandem repeat (VNTR) markers on DNA from bacterial isolates from 98 tissue samples from geographically-distinct populations of these hosts in Idaho, Montana, and Wyoming (O'Brien et al. 2013).
    - Haplotype network assessments of genetic relatedness among *Brucella* isolates suggested substantial interspecific transmission between elk and bison populations in both Wyoming and Montana.
    - *Brucella* genotypes from the 2008 cattle outbreak in Wyoming matched elk *Brucella* genotypes, indicating elk were the likely source. However, *Brucella* from the two recent outbreaks (2008, 2010) in Montana cattle had genotypes similar to both bison and elk. Because wild bison have been excluded from these cattle areas, this finding suggests transmission occurred between bison and elk in Yellowstone in the past, before eventually being transmitted among elk and by elk in the Paradise Valley to cattle.
    - Identical *Brucella* genotypes among many elk populations in Montana suggests that brucellosis may have become established in Montana through intraspecific transmission among populations, without all infected elk originating as immigrants from Wyoming or by transmission from Yellowstone bison.

- Staff from the Animal and Plant Health Inspection Service assessed genetic diversity among 366 field isolates recovered from cattle, bison, and elk in the greater Yellowstone area and Texas during 1998 to 2011 using a variable-number tandem repeat protocol targeting 10 loci in the *Brucella abortus* genome (Higgins et al. 2012).
    - Isolates from a 2005 cattle outbreak in Wyoming displayed profiles matching those of strains recovered from Wyoming and Idaho elk. Additionally, isolates associated with cattle outbreaks in Idaho in 2002, Montana in 2008 and 2011, and Wyoming in 2010 primarily clustered with isolates recovered from elk.
    - This study indicates that elk play a predominant role in the transmission of *Brucella abortus* to cattle located in the greater Yellowstone area.

- Staff from the Animal and Plant Health Inspection Service and Colorado State University evaluated the potential for venereal transmission of *Brucella abortus* in bison by determining if unexposed female bison would become infected following vaginal inoculation or artificial insemination with inoculum containing *Brucella abortus* strain 19 (Uhrig et al. 2013).
    - Four of eight female bison that were intravaginally inoculated seroconverted (i.e., positive for antibodies), indicating exposure of the immune system to *Brucella*, but these animals were culture negative (i.e., not infected) at necropsy six months later.

- Staff from the Animal and Plant Health Inspection Service and Montana Fish, Wildlife & Parks evaluated if Yellowstone bison bulls shed an infective dose of *Brucella abortus* in semen (Frey et al. 2013).

   - *Brucella abortus* was cultured from the semen of three (9%) of 33 seropositive bulls, though not at concentrations considered infective.
   - Eight bulls had lesions of the testes, epididymis, or seminal vesicles consistent with *Brucella abortus* infection.
   - Data suggest that bulls testing positive for *Brucella abortus* were more likely to have non-viable ejaculate (8/33) than bulls testing negative (2/15).

6. Estimate age-specific rates of bison testing seropositive and seronegative for brucellosis that are also culture positive and the portion of seropositive bison that react positively on serologic tests due to exposure to cross-reactive agents other than *Brucella abortus* (e.g., *Yersinia*).

- Staff from the Animal and Plant Health Inspection Service collaborated with colleagues to determine the natural course of *Brucella* abortus infection in female Yellowstone bison and their offspring (Rhyan et al. 2009).
   - Annual seroconversion rates (negative to positive) for brucellosis exposure were relatively high (23%) for calves and juvenile bison, but only 6% for all adult female bison and 11% for adult females that began the study testing negative for exposure.
   - Antibodies for *Brucella* were not protective against infection, even for calves that passively received antibody from an infected mother's colostrum.
   - Antibody levels remained relatively constant, with a slow decrease over time. Only two bison seroconverted from positive to negative for *Brucella* antibodies.
   - Infected bison aborted and shed viable bacteria. Risk of shedding infective *Brucella* was highest for bison during the 2 years following seroconversion from negative to positive.
   - Regardless of serostatus of mothers and their young, most calves were seronegative by 5 months of age. There was no relationship between the antibody status of the mother and the tendency of a calf to convert to positive during the study.

- NPS staff collaborated with colleagues at the University of Montana to investigate if *Yersinia enterocolitica* serotype *O:9* caused false-positive reactions in brucellosis serological tests for bison using culturing techniques and multiplex PCR (See et al. 2012).
   - *Yersinia enterocolitica* was not detected in samples of feces collected from 53 Yellowstone bison culled from the population and 113 free-roaming bison from throughout the greater Yellowstone ecosystem.
   - These findings suggest *Yersinia enterocolitica O:9* cross-reactivity with *Brucella abortus* antigens is unlikely to cause false positive serology tests in bison, and that *Yersinia enterocolitica* prevalence is low in these bison.

- NPS and Animal and Plant Health Inspection Service staff sampled more than 400 bison that were consigned to slaughter during winter 2007-2008 and collected blood and tissues to estimate the proportion of seropositive and seronegative bison that were actively infected with *Brucella abortus* (i.e., culture positive; Treanor et al. 2011).
   - Removing brucellosis-infected bison is expected to reduce the level of population infection, but test and slaughter practices may instead be removing mainly recovered

bison. Recovered animals could provide protection to the overall population through the effect of herd immunity, thereby reducing the spread of disease. Identifying recovered bison is difficult because serologic tests (i.e., blood tests) detect the presence of antibodies, indicating exposure, but cannot distinguish active from inactive infection.

  - Age-specific serology and *Brucella abortus* culture results from slaughtered bison were integrated to estimate probabilities of active brucellosis infection using a Bayesian framework. Infection probabilities were associated with age in young bison (0-5 years old) and with elevated antibody levels in older bison (>5 years old). Results indicate that Yellowstone bison acquire *Brucella abortus* infection early in life, but typically recover as they grow older.
  - A tool was developed to allow bison management to better reflect the probability that particular animals are infective, with the aim of conserving Yellowstone bison while reducing the risk of brucellosis transmission to cattle. Fluorescent polarization assay (FPA) values were higher in seropositive bison that were culture positive compared to seropositive bison that were culture negative, supporting that active infection is associated with increased antibody production.
  - Two covariates (age and FPA) have management application to identify the probability of active infection within specified credible intervals. This would allow for removing bison that most likely contribute to brucellosis maintenance in the population, while keeping bison that contribute to herd immunity and reduce brucellosis transmission.
  - Estimation of true infection probabilities can replace culling practices (such as the slaughter of all seropositive individuals) that conflict with bison conservation. Combining selective removal of infectious bison with additional management practices, such as vaccination, has the potential to advance an effective brucellosis reduction program.

7. Estimate the timing and portion of removals from the central and northern herds each winter, including the portion of removals from each age and sex class and calf-cow pairs.

- NPS staff retrospectively evaluated if reality met expectations by comparing assumptions and predictions for the alternative selected from the Final Environmental Impact Statement and described in the Record of Decision for the IBMP (USDI and USDA, 2000a,b) with observed impacts and changes since implementation of the plan began in 2001 (White et al. 2011).
  - Intensive management near conservation area boundaries maintained separation between bison and cattle, with no transmission of brucellosis.
  - However, brucellosis prevalence in the bison population was not reduced and the management plan underestimated bison abundance, distribution, and migration, which contributed to larger risk management culls (total >3,000 bison) than anticipated.
  - Culls differentially affected breeding herds, altered gender structure, created reduced female cohorts, and temporarily dampened productivity.
  - This assessment was used to develop adaptive management adjustments to the IBMP in 2008 (USDI et al. 2008) and similar future assessments will be essential for

effective management to conserve the largest free-ranging population of this iconic native species, while reducing brucellosis transmission risk to cattle.

8. Document bison use of risk management zones outside the northern and western boundaries of Yellowstone and commingling with livestock during the likely brucellosis-induced abortion period for bison each spring.

- Annual bison use of habitat outside the northern and western boundaries of Yellowstone National Park, and any mingling with livestock, is documented in the annual reports for the Interagency Bison Management Plan (http://ibmp.info/).

- NPS staff collaborated with staff from Colorado State University to develop a state-space model to support decisions on bison management aimed at mitigating conflict with landowners outside the park (Geremia et al. 2014).
    - The model integrated recent GPS observations with 22 years (1990-2012) of aerial counts to forecast monthly distributions and identify factors driving migration.
    - Wintering areas were located along decreasing elevation gradients and bison accumulated in wintering areas prior to moving to areas progressively lower in elevation.
    - Bison movements were affected by time since the onset of snow pack, snow pack magnitude, standing vegetation crop, and herd size. Migration pathways were increasingly used over time, suggesting that experience or learning influenced movements.
    - The model is capable of making explicit probabilistic forecasts of bison movements and seasonal distributions, which allows managers to develop and refine strategies in advance, and promote sound decision-making that reduces conflict as migratory animals come into contact with people.

9. Estimate the effects of hazing or temporarily holding bison in capture pens at the boundary of Yellowstone (for spring release back into the park) on subsequent bison movements or possible habituation to feeding.

- Forty-five bison were captured during winter 2008 at the Stephens Creek capture facility and released in the spring fitted with radio transmitters. The winter movements of these bison (minus mortalities) were monitored during winters 2009 through 2012 to evaluate if the capture and feeding of bison appeared to be influencing future migration tendencies towards the park boundary. Results during these winters with snow packs ranging from mild (2012) to modest (2010, 2013) to severe (2011) suggest few bison are habituated to hay provided at the Stephens Creek capture facility and most bison do not migrate to lower elevations to seek forage until deep snow accumulates at higher elevations (Table 1).

Table 1. Winter movements of radio-marked bison after release from the Stephens Creek capture facility in spring of 2008.

	Winter 2009	Winter 2010	Winter 2011	Winter 2012	Winter 2013
Percent of marked bison returning to the Gardiner basin	12 of 40 = 30%	2 of 38 = 5%	28 of 34 = 82%	5[1,2] of 29 = 17%	9 of 26 = 34%
Percent of marked bison returning to the Blacktail Deer Plateau, but not migrating as far as the Gardiner basin	16 of 40 = 40%	12 of 38 = 32%	5 of 34 = 15%	18 of 29 = 62%	9 of 26= 34%
Percent of marked bison that remained on interior ranges of the park	10 of 40 = 25%	20 of 38 = 53%	0 of 34 = 0%	6 of 29 = 21%	6 of 26 = 23%
Percent of marked bison that migrated to the west boundary of the park	2 of 40 = 5%	4 of 38 = 11%	1 of 34 = 3%	3[1] of 29 = 10%	2 of 26 = 8%

[1] Three of these bison first migrated to the north boundary before moving to the west boundary later in the winter and were included in both calculations.
[2] Only one of these five bison moved as far north as the Stephens Creek facility during this winter period.

Brucellosis Suppression (Reduce Brucellosis Prevalence)

10. Determine the strength and duration of the immune response in bison following vaccination for brucellosis via a hand-held syringe.

- Through the Civilian Research and Development Foundation, the NPS provided cooperative funding to key Russian vaccine experts to develop the first comprehensive review of scientific laboratory and field studies on the primary Russian brucellosis vaccine derived from *Brucella abortus* strain 82 (SR82), and publish this report in an English language peer-reviewed scientific journal (Olsen et al. 2010, Ivanov et al. 2011).
    - The smooth-rough strain SR82 vaccine combines the desired weak responses on standard tests with high efficacy against brucellosis.
    - In 1974, prior to widespread use of strain SR82 vaccine, more than 5,300 cattle herds were known to be infected with *Brucella abortus* across the former Soviet Union.
    - By January 2008, only 68 cattle herds in 18 regions were known to be infected, and strain SR82 continues to be the most widely and successfully used vaccine in many regions of the Russian Federation.

- NPS staff collaborated with colleagues from the Animal and Plant Health Inspection Service and Montana State University to measure the cell-mediated immune responses (CMI) induced by SRB51 vaccination in bison (Treanor 2012).
    - During winter 2008-2009, 12 yearling bison in the quarantine feasibility study were vaccinated by syringe with SRB51. Immune responses were assessed prior to vaccination and at 3, 8, 12, 18, and 21 weeks after vaccination.
    - Additionally, 20 wild, yearling, female bison were captured at the Stephens Creek facility during late winter 2008 and 14 of these bison were vaccinated by syringe with SRB51, while six served as non-vaccinated controls. The CMI response of the vaccinated bison was analyzed at 2 and 6 weeks post vaccination. Thereafter, all 20 bison were released back into the wild during May 2008. During autumn and winter

2008-2009, 14 of the 20 bison in the study were recaptured to measure CMI responses 24+ weeks following vaccination.
  - Comparison of the immune responses following vaccination with *Brucella abortus* strain RB51 in captive and free-ranging bison indicated a single vaccination of SRB51 may offer some protection in approximately 50% of vaccinated yearling female bison.
  - Overall, immune responses following vaccination were similar between both study groups, including the proportion of individuals within each study group that showed either strong, weak, or essentially no response following vaccination. This individual variation is expected to reduce vaccine efficacy when vaccination is applied at the population level.
  - Factors such as seasonal food restriction and loss of body reserves may play an important role in the effectiveness of wildlife vaccination programs. Protective immune responses induced through vaccination may be limited if vaccines are delivered to undernourished animals.

11. Determine the strength and duration of protective immune response in bison following vaccination for brucellosis via remote delivery (i.e., without capture; e.g. bio-bullet).

- During 2003-2005, NPS staff collaborated with Colorado State University and the Agricultural Research Service to develop procedures for vaccine encapsulation and maintaining the structural consistency of projectiles. This effort demonstrated successful proof-of-concept for delivering a degradable ballistic brucellosis live vaccine remotely to bison from a distance of 40 meters using commercial components and a novel hydrogel vaccine carrier (Christie et al. 2006).

- Olsen et al. (2006a,b) reported the ballistic inoculation of bison with bio-bullets containing photopolymerized, polyethylene glycol-based hydrogels with SRB51 induced a significant cell-mediated immune response similar to syringe injection of the vaccine. However, a second vaccination trial on bison during 2007 indicated poor immunologic proliferation and interferon response compared to syringe injection (S. Olsen, Agricultural Research Service, unpublished data). Results also demonstrated bio-bullet failure with projectiles fracturing or being too soft to penetrate the skin of vaccinates. These inconsistencies between studies regarding the cell-mediated immune responses observed following hydrogel vaccination of bison with SRB51 may have been due to differences in the photopolymerization process used to encapsulate vaccine in projectiles.

- NPS staff collaborated with the University of Utah and the Agricultural Research Service to develop a protocol for pursuing minor enhancements to the vaccine payload performance and the ballistic delivery system under quality controlled production prior to field test on bison. It will also involve (1) negotiating supply agreements with various reagent vendors, (2) developing scientific and technical protocols to facilitate technology transfer to a contractor who can procure and produce the entire vaccine component line, (3) initiation and supervision of a production program for bio-bullet vaccine formulations under quality systems validation, and (4) final delivery of ready-to-use bio-bullet vaccine formulations and protocols for field use (Grainger 2011).

12. Document long-term trends in the prevalence of brucellosis in bison, and the underpinning effects of remote and/or syringe vaccination, other risk management actions (e.g., harvest, culling), and prevailing ecological conditions (e.g. winter-kill, predation) on these trends.

- During 2007-2009, NPS staff developed a fully functional wildlife health laboratory in the basement of the Heritage and Research Center for the processing of biological samples and the direct or indirect measurement of disease organisms, immunological indicators, or indicators associated with animal health (e.g., metabolites and hormones).
  - This laboratory enables NPS staff to maintain sample quality, get timely results, and increase sample sizes. Equipment has been used to culture cells to measure immune responses of brucellosis vaccination in bison and conduct fluorescence polarization immunoassays of serological samples for the diagnosis of brucellosis exposure.
  - The laboratory is certified as a biosafety level 2 facility, which is important for brucellosis vaccination work. However, no work is conducted directly on zoonotic disease agents (e.g., *Brucella abortus*).

- NPS staff collaborated with colleagues at the U.S. Geological Survey and Montana State University to estimate how much time (years) it takes to detect a change in seroprevalence in bison over time using three analytical approaches: the single year estimate; the 3-year running average; and regression using all years to date (Ebinger and Cross 2008).
  - Capture and sampling of more than 200 bison during a given year would be necessary to detect significant changes in seroprevalence following vaccination, and detection would likely take 5-20 years depending on sample sizes and detection method.
  - The ability to detect a change in seroprevalence is a function of the (1) amount of decrease in seroprevalence, (2) shape of the seroprevalence decrease curve, and (3) the sample sizes used for estimating seroprevalence. The ranges of possibility for the amount of decrease in seroprevalence and for the shape of the decrease curve are relatively unknown.
  - The single-year estimate approach consistently showed more variation around the median. The regression model tended to be a more powerful approach, though there was more variation around this estimate for the slower decreases in prevalence.
  - The probability of detecting a difference between the baseline and some future point in time increases as you increase the number of individuals periodically tested. An annual testing increment of fewer than 200 individuals provides a poor probability of detecting a decrease in seroprevalence to below 40%. Conversely, sampling at much greater numbers than 250 individuals does not significantly improve the probability of precision in detecting a change in seroprevalence.

- NPS staff collaborated with colleagues at the University of Kentucky to develop an individual-based model to evaluate how brucellosis infection might respond under alternate vaccination strategies, including: 1) vaccination of female calves and yearlings captured at the park boundary when bison move outside the primary conservation area; 2) combining boundary vaccination with the remote delivery of vaccine to female calves and yearlings distributed throughout the park; and 3) vaccinating all female bison (including adults) during boundary capture and throughout the park using remote delivery of vaccine (Treanor et al. 2010).

  - Simulations suggested Alternative 3 would be most effective, with brucellosis seroprevalence decreasing by 66% (from 0.47 to 0.16) over a 30-year period due to 29% of the population receiving protection through vaccination.
  - Under this alternative, bison would receive multiple vaccinations that extend the duration of vaccine protection and defend against recurring infection in latently infected animals.
  - The initial decrease in population seroprevalence will likely be slow due to high initial seroprevalence (40-60%), long-lived antibodies, and the culling of some vaccinated bison that were subsequently exposed to field strain *Brucella* and reacted positively on serologic tests.
  - Vaccination is unlikely to eradicate *Brucella abortus* from Yellowstone bison, but could be an effective tool for reducing the level of infection.

- NPS staff prepared a Draft Environmental Impact Statement to decide whether or not to proceed with implementation of remote delivery vaccination of bison in the park. Three alternatives were included in the document (USDI, NPS 2010):
  - The no action alternative described the current vaccination program that is intermittently implemented at the Stephens Creek capture facility in concert with capture operations. The second alternative would include a combination of the capture program at Stephens Creek and a remote delivery vaccination strategy that would focus exclusively on young, non-pregnant bison of both sexes. Remote delivery vaccination could occur from March to June and mid-September to mid-January through many areas of bison distribution in the park. A third alternative would include all components of the second alternative, as well as the remote vaccination of adult females during autumn. The vaccination program is intended to lower the percentage of bison susceptible to brucellosis infection.
  - The Notice of Availability for the Draft Environmental Impact Statement was published in the Federal Register (75 FR 27579) on May 17, 2010. The comment period was from May 28, 2010 to September 24, 2010. Also, NPS staff conducted three public meetings to gain information from the public on the park's purpose and significance, issues, and alternatives presented in the Draft Environmental Impact Statement. These meetings were held in Bozeman, Montana on June 14, 2010, Helena, Montana on June 15, 2010, and Malta, Montana on June 16, 2010.
  - The NPS received a total of 1,644 correspondences via letters, electronic mail (email), faxes, comments from public meetings, park forms, and web forms. These correspondences were distilled into 9,410 individual comments. From this correspondence, the NPS in collaboration with Weston Solutions, Inc. identified 6,629 substantive comments, which were divided into 26 concern statements.
  - Most respondents associated with conservation constituencies opposed the remote vaccination program and recommended vaccination of cattle rather than bison. Conversely, most respondents associated with livestock groups supported vaccination. Many respondents suggested that the projected cost of park-wide remote vaccination was too expensive to justify the benefits. A few constituency groups initiated letter writing campaigns to suggest re-directing funding to purchase grazing

opportunities from private landowners outside Yellowstone National Park. Many respondents disputed the scientific information presented in the draft Environmental Impact Statement or suggested that inadequate scientific information existed to justify a decision to implement remote vaccination.

- The American Bison Society commissioned an objective review of diseased bison issues and management approaches in the greater Yellowstone and Wood Buffalo areas (Nishi 2010).
    - The disease issues in these bison have not been resolved because of their dynamic epidemiology and the conflicting mandates and views held by various government agencies and stakeholders regarding what should be done and what can be done to conserve bison and manage disease risk. What should be done is based on mandates, values, and viewpoints regarding conservation versus risk, while what can be done is based on existing conditions and technologies, as well as biological feasibility and economic costs.
    - When considering what can be done, managers should consider four potential disease management objectives, including: 1) do nothing; 2) prevent transmission to unaffected populations; 3) control the prevalence and spread of infection; and 4) eradication.
    - Management decisions regarding bison with zoonotic diseases should be informed by research on political and socioeconomic factors such as the (1) comparative costs and public preferences for various management alternatives, (2) non-market values of wild bison, (3) the demand for bison that are removed from the population, and (4) public attitudes, behaviors, and knowledge of bison, brucellosis, and management.
    - Best management practices should be applied within a risk framework as part of a three-pronged strategy that also includes an adaptive management process and an evaluation and refinement of livestock and wildlife policies.
    - One way forward is to focus on improving collaborative relationships and institutionalizing adaptive management processes by: 1) providing a forum and funding for a long-term process to address the issue; 2) developing and using systems thinking skills and diverse modeling tools; 3) working across boundaries; and 4) engaging stakeholders.
    - Letting the bison disease issues be determined through inaction is not an appropriate management strategy. Practices to contain and lessen disease risk should be continued and improved while working towards a long-term solution.

- NPS staff collaborated with colleagues at the U.S. Geological Survey and Montana State University to use an individual-based epidemiological model to assess the relative efficacies of three management interventions (sterilization, vaccination, and test-and-remove; Ebinger et al. 2011).
    - Sterilization and test-and-remove were most successful at reducing brucellosis prevalence when they were targeted at young seropositive animals, which are the most likely age and sex category to be infectious. However, sterilization and test-and-remove also required the most effort to implement. Vaccination was less effective, but required less effort to implement.

    - The sterilization of 50-100 females per year had little impact on the bison population growth rate when selectively applied and the population growth rate usually increased by year 25 due to the reduced number of brucellosis-induced abortions.
    - Initial declines in seroprevalence followed by rapid increases occurred in 3-13% of simulations with sterilization and test-and-remove, but not vaccination. This may be due to the interaction of super-spreading events (e.g., one abortion event infects many susceptible bison) and the loss of herd immunity in the later stages of control efforts.
    - Vaccination reduces seroprevalence while maintaining herd-immunity and minimizing the occurrence of super-spreading events. Sterilization and test-and-remove reduce herd-immunity and super-spreading events become more common as the population becomes more susceptible.
    - Sterilization provided a mechanism for achieving large brucellosis reductions while simultaneously limiting population growth, which may be advantageous in some management scenarios. However, the field effort required to find the small segment of the population that is infectious rather than susceptible or recovered will likely limit the utility of this approach in many free-ranging wildlife populations.

- An NPS biologist published a dissertation (Treanor 2012) that reported findings on the maintenance of brucellosis in Yellowstone bison, including links to seasonal food resources, host-pathogen interaction, and life-history trade-offs.
    - Active brucellosis infection was associated with below-average nutritional condition, with the intensity of *Brucella abortus* infection being influenced by seasonal reductions in dietary protein and energy.
    - The reproductive strategy of Yellowstone bison is linked with the seasonal availability of food, which increases bison fitness but may have consequences for *Brucella abortus* infection. Seasonal food restriction may also influence the ability of vaccinated bison to recall protective immune responses when later exposed to *Brucella abortus*.
    - The rate of fat metabolism was an important factor influencing the cell-mediated immune response (interferon-γ production). Thus, individual variation and the seasonal availability of food may reduce vaccine efficacy when vaccination is applied at the population level.

- During February 2012, NPS managers representing park, regional, and service-wide perspectives met and discussed the applicability and feasibility of using fertility control as an ungulate management tool in NPS units. A review of pertinent scientific information with presentations by experts in fertility control technologies, wildlife population modeling, and moral and ethical considerations preceded the discussion. Guidance for the use of fertility control on ungulates within NPS units, included (Powers and Moresco 2013):
    - Fertility control may be useful, valid, and desirable under certain circumstances, especially in small, closed populations of habituated or easily accessible ungulates.
    - Fertility control is more acceptable for non-native species, but could be considered for native species in highly altered or manipulated environments where the influences of humans are prevalent.

- Wildlife are public trust resources and the NPS must consider input from a broad spectrum of stakeholders (including state and federal management agencies) and make decisions within the context of the enabling legislation for the NPS and individual park units.
- Each park unit should have well-defined, explicit goals for managing ungulates and the processes that sustain them, and there should be substantial information regarding demography and ecology to forecast (e.g., model) the effects and success of the program. Evidence must indicate a fertility control program will have few negative effects on native species and the ecosystem. Long-term monitoring and adaptive management are essential for success.
- Potential methods for fertility control should: 1) minimize the need for repeat treatments (i.e., high efficacy and appropriate duration); 2) be safe for the individual animal (i.e., minimal negative side-effects); 3) be safe for humans or scavengers that might consume the animal (i.e., no food chain concerns); 4) be regulated for use in a management context; and 5) be practical and feasible for use (i.e., easy to deliver and relatively inexpensive; Powers and Moresco 2013).

- Economists in Wyoming worked with biologists and the State Veterinarian to evaluate feasible management strategies with cattle and wild elk to reduce brucellosis prevalence and transmission risk. They found that implementing preventative actions (e.g., vaccination, test-and-slaughter, hazing) with either cattle or elk were not cost-effective when compared to the cost of an occasional brucellosis outbreak in cattle (Roberts et al. 2012, Kauffman et al. 2013). These results are at least qualitatively relevant to the management of bison and elk in the northern Yellowstone area because many of the same management techniques have been proposed.
  - Cattle producers in the Yellowstone area that want to reduce the risk of their herds contracting brucellosis from wildlife due to the economic costs of an outbreak can take several actions, including (1) fencing haystacks, (2) hazing elk from their property, (3) booster vaccinating adult cattle, (4) spaying heifers, (5) modifying winter feeding schedules, (6) delaying cattle release on summer grazing allotments, and (7) preventing the mingling of cattle and wildlife. Implementing these preventative actions was not cost-effective for cattle producers with herds that faced relatively little risk of brucellosis exposure from elk and costs due to exposure (Roberts et al. 2012).
    - Adult booster vaccination of cattle with current vaccines would have to reduce the risk of a brucellosis outbreak by almost 200% (which is impossible) to be cost-effective for a producer whose herd faces a 1% chance of contracting brucellosis annually.
    - Only when economic costs due to an outbreak approached $140,000 or risk increased to relatively high levels (e.g., 10-50% per year) was it even effective to implement the least-expensive preventative actions such as hazing wildlife and fencing haystacks.
  - Three management strategies that could be implemented with wild elk to increase the number of years until a brucellosis outbreak in cattle occurs include: 1) test-and-slaughter by capturing elk and removing animals testing positive for brucellosis exposure; 2) vaccination of calf elk with strain 19; and 3) low-density feeding of elk

to avoid aggregations. However, the costs of these management strategies would be extremely high relative to the benefits (Kauffman et al. 2013).

    - The costs of a brucellosis outbreak in cattle would need to be about $20 million to equal the costs of conducting test-and-slaughter in elk to reduce brucellosis prevalence from about 18% to 5%.
    - The costs of a brucellosis outbreak in cattle would need to be about $8 million to equal the costs of vaccination in elk to reduce brucellosis prevalence by 1% (i.e., to 17%).
    - The costs of a brucellosis outbreak in cattle would need to be about $560,000 to equal the costs of conducting low-density feeding of elk to reduce brucellosis prevalence by 10% (i.e., to 8%).

- NPS staff and brucellosis experts from around the world contributed articles to *Brucellosis: Recent Developments Towards 'One Health*' by the World Organization for Animal Health to support finding practical and effective solutions for addressing brucellosis at local, regional, and global levels (Plumb et al. 2013).
    - An article entitled *Brucellosis in Terrestrial Wildlife* (Godfroid et al. 2013) suggested:
        - There is no brucellosis vaccine with satisfactory efficacy and safety in wildlife. The development of new vaccines, diagnostics, and management practices will be necessary to effectively control brucellosis.
        - Brucellosis control in wildlife should be based almost exclusively on good management practices, with a combination of novel management strategies and public education to balance conservation, economic, and public health issues.
        - It is amazing that the epidemiology and ecology of brucellosis infection in wildlife are still so poorly understood.
        - Transmission of *Brucella* from wildlife to humans seems to be limited to the dressing and butchering carcasses.

    - An article entitled *Recent Developments in Livestock and Wildlife Brucellosis Vaccination* (Olsen 2013) suggested:
        - Available vaccines generally do not prevent infection, can induce abortions, and are infectious to humans. There is a great need for improved brucellosis vaccines due to the re-emergence of brucellosis world-wide.
        - *Brucella* has multiple mechanisms that weaken immunity and minimize immune responses.
        - Vaccine-induced antibody responses in the blood serum (plasma) are not indicative of long-term protective immunity for the animal, and instead, investigators should measure increases in specific T cells that produce cytokines such as interferon-γ, interleukin-2, and tumor necrosis factor-α.
        - Currently, three vaccines (strains 19, 82, and RB51) are used world-wide to provide bison, cattle and elk with some resistance to *Brucella abortus*. These vaccines consist of live, weakened strains of the bacteria because, to date, experiments with vaccines consisting of heat-killed or subcellular fractions of the bacteria have not induced substantial protective immune responses.
        - Strain 19 and RB51 vaccines provide little or no protection to elk against brucellosis infection and transmission because vaccinated animals do not develop

cellular immune responses. Also, strain 19 induces abortions in adult bison and does not appear to provide much protection to vaccinated calves.
    - Strain RB51 provides some protection against infection and abortion in vaccinated bison and cattle, especially when they receive a subsequent booster vaccination. All of these vaccines are most effective at suppressing brucellosis when combined with a strategy of culling individuals testing positive for brucellosis infection.
- An article entitled *Risks of Brucella abortus spillover in the greater Yellowstone area* (Schumaker 2013) suggested:
    - All brucellosis transmissions to cattle in the greater Yellowstone area since 2004 were epidemiologically or genetically traced to wild elk.
    - The risk of brucellosis transmission from wildlife to cattle depends on (1) the prevalence of the disease in wildlife, (2) the size and location of wildlife and cattle populations, (3) the number of interactions between livestock and wildlife living in close proximity, and (4) the susceptibility of livestock to infection.
    - The risk of transmission to cattle from bison is negligible because of natural movements by bison to higher elevation summer ranges and management that successfully limits commingling.
    - For decades, disease regulators believed that brucellosis would not persist in elk throughout the greater Yellowstone area without frequent transmission from infectious Yellowstone bison or elk dispersing from feed grounds in Wyoming. However, recent surveillance indicates elk in many areas support the disease independently of bison or feed-ground elk.
    - There appears to be little risk of bison transmitting brucellosis to elk, but significant risk of elk exposing bison to infectious birth material.
    - The risks of brucellosis transmission are primarily from wild elk that are allowed to mingle with cattle, and management to suppress brucellosis in bison will not substantially reduce the far greater transmission risk from elk.
    - Management should focus on decreasing densities and group sizes of elk and understanding the behavioral and environmental factors that result in comingling with cattle that makes brucellosis transmission possible.
- An article entitled *An Ecological Perspective on Brucella abortus in the Western United States* (Cross et al. 2013) suggested:
    - Recent occurrences of brucellosis transmission from elk to cattle appears to be due to increases in brucellosis prevalence in elk populations and elk contacts with livestock on shared winter ranges.
    - Brucellosis transmission is facilitated by animals aggregating in close proximity (e.g., 100 to 500 meters) during January to June when most abortions and infectious live births occur.
    - Management actions should maintain separation between bison and cattle, while attempting to decrease elk density and group sizes in areas where mingling with cattle occurs.
    - Even though vaccines are often touted as a tool that could substantially reduce brucellosis transmission in wildlife in the greater Yellowstone ecosystem and elsewhere, their use remains limited by financial, logistical, scientific, and social constraints.

- There is no easily delivered, highly effective, and safe vaccine for elk. Elk on feed grounds in Wyoming have been vaccinated with strain 19 since 1985, with no reduction in brucellosis prevalence or abortions.
- It would be extremely difficult and cost-prohibitive to deliver vaccine to bison and elk distributed across an area as large as the greater Yellowstone ecosystem until a more passive or natural delivery to these specific species is feasible.
- Brucellosis suppression efforts would need to be coordinated across the jurisdictions of agencies with different mandates and maintained for many decades in at least two species (bison, elk) capable of independently transmitting and sustaining the disease.
- Managers should eliminate practices that unnaturally increase elk aggregations and group sizes near cattle during the potential abortion and calving period for elk, perhaps by using harvests and/or predators to distribute elk.
- Management options to reduce the risk of brucellosis transmission from elk to cattle include (1) the development of herd management plans and modifications of habitats to minimize spatial and temporal overlap of cattle and elk in areas where brucellosis transmission risk is high, (2) targeted hunts during late winter to redistribute large aggregations of elk on winter ranges shared with cattle, (3) tolerance for predators and scavengers that remove infectious birth tissues and limit the duration and spread of infection, and (4) shortening the supplemental feeding season in Wyoming and delivering feed over a larger area.

o An article entitled *Integrating Ecology with Management to Control Brucellosis* (Treanor 2013) suggested:

- Continued culling of large numbers of Yellowstone bison to decrease the risk of brucellosis transmission to cattle could adversely affect the conservation of bison over time.
- Food restriction during winter, which also corresponds with late gestation, can limit resources available for immune defense and may be an important factor sustaining brucellosis in wild bison and elk.
- Management needs to integrate a wide range of methods, including maintaining separation between cattle and wildlife, managing habitat to reduce brucellosis transmission, and decreasing brucellosis prevalence in wildlife.
- One strategy would be to vaccinate as many bison as possible for many years to reduce brucellosis prevalence, especially in the young, pre-reproductive ages. After prevalence decreases substantially in young bison, managers could then use probabilities of active infection based on serum antibody levels and bison age to remove animals with a high risk of shedding bacteria, which should be a relatively small portion of the population.
- This strategy should increase population-level resistance to brucellosis through vaccination and retaining animals that were previously exposed to *Brucella* bacteria but are no longer infectious, without culling large numbers of animals.

o An article entitled *Bovine Brucellosis in Wildlife: Using Adaptive Management to Improve Understanding, Technology and Suppression* (White et al. 2013d) suggested:

- Eradication of brucellosis from bison and elk populations in the greater Yellowstone area is not possible or practical with current technology without resorting to ethically and politically unacceptable techniques such as mass test-and-slaughter or depopulation.

    - Adaptive management provides a framework for substantially lowering brucellosis prevalence in wildlife in the face of substantial uncertainties regarding the effectiveness of management techniques and unintended effects on wildlife behavior and demography. Through careful predictions and monitoring of these management actions, our understanding of bison and brucellosis will be improved and actions can be adjusted to better achieve desired outcomes.
    - Since it takes approximately 3 years after birth for female bison to become reproductively active and contribute to brucellosis transmission, there is an opportunity to implement management actions such as vaccination combined with the selective removal of likely infectious bison based on age and assay results to reduce transmission potential. Bison that have been exposed to the bacteria, but recovered from acute infection, could be retained in the population to provide herd immunity.

- In February 2013 a panel of scientists from federal, state, academic, and non-governmental entities (1) reviewed what is known about the vaccine-induced immune responses of bison and elk, (2) reviewed the benefits and limitations of existing tools and emerging technologies for suppressing brucellosis prevalence in bison and elk, (3) evaluated whether substantial brucellosis suppression is feasible and sustainable without significantly affecting bison behavior or visitor experience, and (4) provided ideas regarding the future direction of brucellosis suppression activities (including suitable tools, research, and surveillance), considering that the primary mission of the park is to preserve its cultural and natural resources for the benefit of the American people (USDI, NPS and Montana Fish, Wildlife & Parks 2013). At the close of the workshop, the participants shared four consensus conclusions:
  - *On the merits and need for remote vaccination of free-ranging bison:* Best available data does not support that remote vaccination of bison with the currently available vaccines will be an effective tool for suppressing brucellosis in wild bison to a level that changes the IBMP management strategies. Available data also suggest remote vaccination will be a very cost ineffective tool for preventing brucellosis spillover to cattle.
  - *On the potential ecological impacts of remote vaccination:* In addition to the foregoing main conclusion that an aggressive remote vaccination campaign for free-ranging bison cannot be justified based on available data, we also discussed other potential collateral consequences of such a program. Our distilled summary of this discussion is as follows:
    - We anticipate that remote vaccination would have behavioral impacts on bison (e.g., reduced tolerance of people, vehicles, etc.).
    - Reduced tolerance for humans and vehicles could lead to shifts in the spatial distribution of bison with resulting effects on landscapes used more or less by bison.
    - Reduced tolerance for humans and vehicles also could have impacts on opportunity for visitors to observe bison and could change how bison react to visitors.

        - Changes in bison behavior and distribution also could have secondary impacts on predator-prey relationships (e.g., increase pressure on other species) and on scavenger relationships.
        - If vaccination were successful in reducing brucellosis in bison, then the net demographic effect would be to increase the bison population (by reducing abortions and increasing annual birth rate). Because it is unlikely that vaccination would eliminate brucellosis completely, we anticipate that such an increase in bison numbers could increase the efforts and fiscal expenditures necessary to maintain effective spatial-temporal separation of bison and cattle.
    - *On the use of culling in disease and bison population management:* Control of the bison population size will most likely include culling or removal, along with hunting, as the main management tools. Past and current culling practices (which have been largely nonselective and opportunistic) have not had an apparent effect on reducing overall bison herd seroprevalence (around 50%). We recognize the potential to use culling as a tool for both interspecies disease risk management and bison population control.
    - *On the use of fertility control in disease and bison population management:* To achieve the current goals of the disease management plan, intervention with contraception is not needed. However, we acknowledge that fertility control could become a tool for disease control if treated females returning to reproductive status are no longer infectious despite exposure to brucellosis. The available data are insufficient to make a judgment at this time, but we encourage continuation of ongoing research in this area. Experimental results should be combined with modeling to scale contraception effects up to the population level and evaluate this as an alternative disease control approach.

- Scientists from the U.S. Geological Survey, NPS, and Colorado State University evaluated the efficacy of fertility control as a way to regulate the abundance of wildlife populations (Ransom et al. 2013).
    - Contraception may produce unintended changes in birth, survival, immigration, and emigration rates that decrease the effectiveness of population regulation. The extent and frequency of such effects depends on the specific social and reproductive systems, as well as connectivity with other populations.
    - Fertility control can induce changes in survival and immigration that compensate for the reduction in births caused by contraception. Applications of contraceptives to small, closed populations of wildlife that aggregate and are easily accessed may be more successful in regulating abundance.
    - Fertility control can result in artificial selection pressures that lead to unintentional genetic consequences. The extent of this selection depends on individual heritability, behavioral traits, and environmental variation.
    - Before they expend time, effort, and funding in wildlife contraception, they should consider that many wildlife populations can compensate for a reduction in fecundity, and minimize any reduction in population growth rate.

- Based on their analyses and an evaluation of public and expert scientist comments, NPS biologists recommended to the Superintendent of Yellowstone National Park in 2013 that the implementation of park-wide remote vaccination at this time would likely not achieve desired results and could have unintended adverse effects to the bison population and visitor experience due to:

- Our limited understanding of bison immune responses to brucellosis suppression actions such as vaccination;
- The absence of an easily distributed and highly effective vaccine (e.g., 10-15% reduction in infection; short duration of immune protection; cannot vaccinate females in second half of pregnancy);
- Limitations of current diagnostic and vaccine delivery technologies (e.g., inconsistent vaccine hydrogel formulation; short rifle range; no rapid diagnostics for live animals);
- Effects of bison nutrition, condition, and pregnancy/lactation that lessen protective immune responses from vaccination;
- Potential adverse consequences (e.g., injuries; changes in behavior) to wildlife and visitor experience (e.g., wildlife viewing) from intrusive brucellosis suppression activities (e.g., capture; remote vaccination); and
- Chronic infection in elk which are widely distributed and would almost certainly re-infect bison (USDI, NPS 2014).

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